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OFFICE OF SCIENTIFIC RESEARCH & DEVELOPMENT

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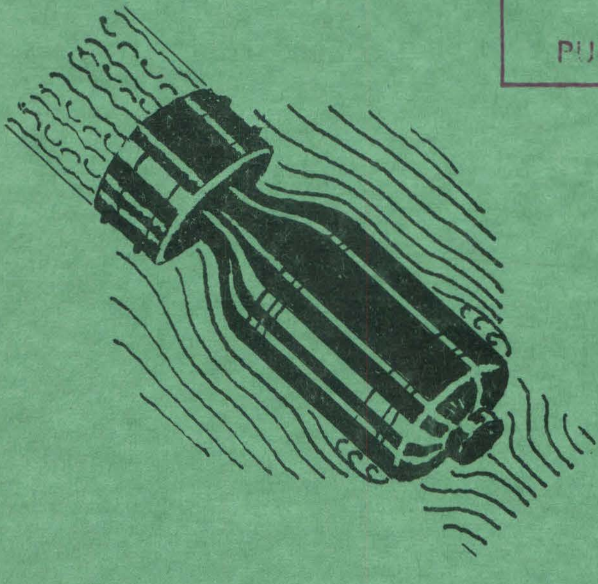
WATER TUNNEL TESTS

OF THE

60 MM. MORTAR PROJECTILE



THE HIGH SPEED WATER TUNNEL

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA.

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ND20

SECTION № 6.1-sr-207-926

ND-20

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OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION SIX — SECTION 6.1

WATER TUNNEL TESTS OF THE 60 MM. MORTAR PROJECTILE

BY

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THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRAULIC MACHINERY LABORATORY
PASADENA, CALIFORNIA

[redacted]

Section No. 6.1-sr207-926
HML Rep. No. ND-20

September 2, 1943

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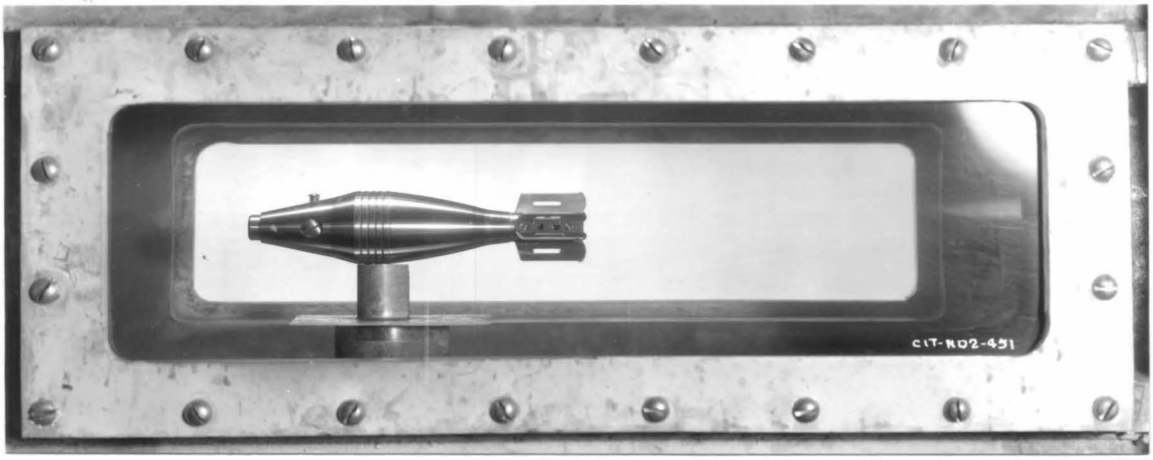

2" DIAMETER MODEL OF THE 60 MM. MORTAR PROJECTILE
IN THE
HIGH SPEED WATER TUNNEL

The High Speed Water Tunnel is operated by the California Institute Of Technology under contract OEMsr-207 and is sponsored by Division 6, Section 6.1 of the NDRC. The tests reported herein were made at the request of Colonel Lester E. Simon of the Aberdeen Proving Ground, Maryland.

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OF THE
60 MM. MORTAR PROJECTILE

SUMMARY

1. The projectile as submitted is quite unstable due to the location of the center of gravity so far aft of the nose. This condition could be greatly improved by making the nose of metal instead of plastic. The tests illustrate how intimately the position of the C.G. is related to stability. Only one of the changes tested failed to increase the stability of the projectile.

2. Extending the tail aft by means of a 1-1/2" boom will add greatly to stability without increasing the drag materially. The effect of this on the interior ballistics of the mortar has not been investigated.

3. A 1-5/16" diameter disc at the rear of the fins would give greater stability than the 1-1/2" boom, but the drag would be increased 70%. This increased drag would probably reduce the range from 10% to 25% depending on the velocity. A 1-1/8" diameter disc would increase the drag about 30% and would have a materially stabilizing effect due to the increased moment and greater center of pressure eccentricity but would not be as stable as the 1-5/16" disc.

4. The stability of projectiles that are now on hand could be increased by the addition of a thin disc held in place by the primer assembly.

5. It is suggested that a number of projectiles be equipped with discs as described in paragraph 4 in order to determine performance under actual conditions. Both the plain and notched discs should be tried.

6. All tests show that the center of pressure location is very sensitive to any changes in the projectile with consequent effect on the stability. It is imperative, therefore, that no other changes than those herein recommended can be made in the projectile if the test results are to apply. If additional changes seem desirable, a new series of tests should be made in order to predict performance.

(The above boom and disc dimensions refer to the model).

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WATER TUNNEL TESTS

OF THE

60 MM. MORTAR PROJECTILE

(Laboratory Designation ND-20)

GENERAL DESCRIPTION

This report covers Water Tunnel tests of a 2" diameter model of the 60 mm. mortar projectile. These tests were conducted for the purpose of determining the performance characteristics of the projectile as constructed and, if possible, devising some means for increasing its stability in flight. The tests consist of observing the drag, cross force, and moment on the model in the High Speed Water Tunnel and from these observed data, deriving the performance characteristics.

Appendix "A" gives a description of the various terms and symbols used as well as a brief discussion of the requisite conditions for stability in a projectile. Appendix "B" gives a description of what has been termed the "Characteristic Chart". This is useful in determining the relative performance of various modifications in the design.

Twenty-eight separate runs were made on the model. These included tests of an exact model of the prototype and of modifications made by many changes in the tail design.

The curve sheets, Figures 14, 15, and 16, give the calculated coefficients based on faired curves of the observed data.

The Flow Line Drawings (Figures 18 to 29) show the model with various tail modifications and at 0° and 10° yaw. These drawings are based on detailed observations of the model in the Polarized Light Flume.

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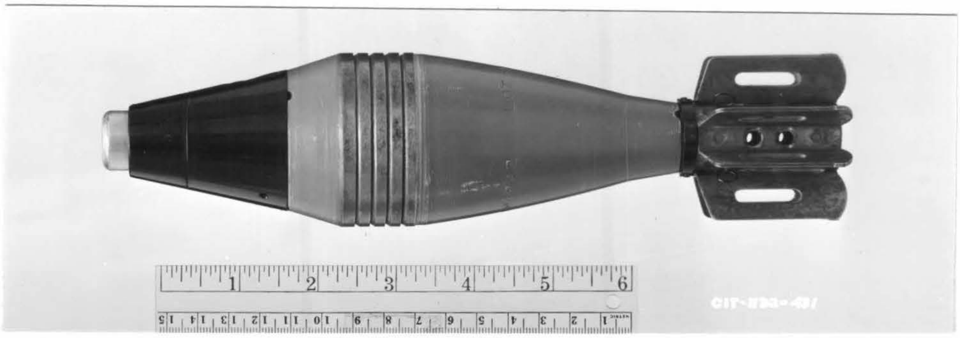

FIGURE 1

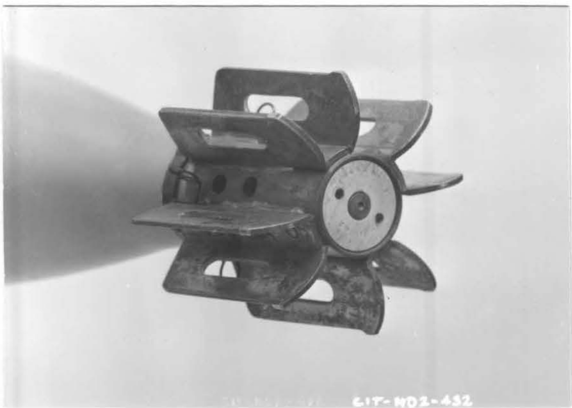

FIGURE 2

FIGURE 3

60 MM. MORTAR PROJECTILE

[redacted]

DESCRIPTION OF PROJECTILE

The 60 mm. mortar projectile is shown in Figures 1, 2, and 3. The nose, containing the fuze assembly, is of plastic, the body containing the H.E. charge, is of steel and to this is screwed the tail assembly. The tail consists of eight fins attached to a hollow hub into which is inserted the propellent cartridge. The fins are provided with spring clips which are designed to hold increment propellent wafers for increasing the range.

The physical properties of the projectile are as follows:

Length overall	9.54"
Diameter	2.362"
Weight as fired	2.90 lbs
Nose to center of gravity	4.66"
Center of gravity	.488 of length

Approximate performance data:

	Velocity (ft/sec)	Range at 45° (yards)
Cartridge only	225	488
Cartridge plus 1 wafer	313	881
Cartridge plus 2 wafers	387	1258
Cartridge plus 3 wafers	458	1644
Cartridge plus 4 wafers	518	1984

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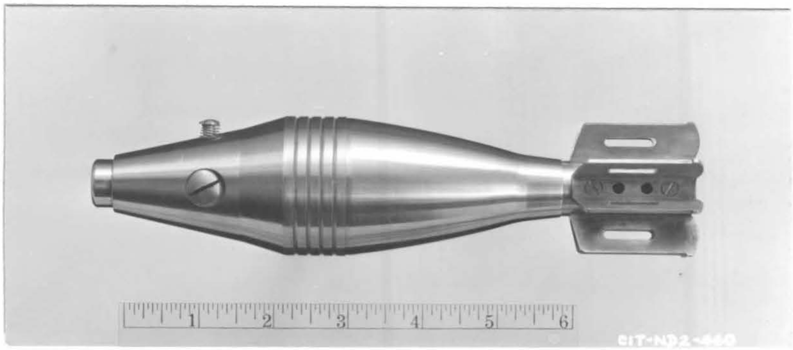

FIGURE 4
MODEL WITH
PROTOTYPE NOSE

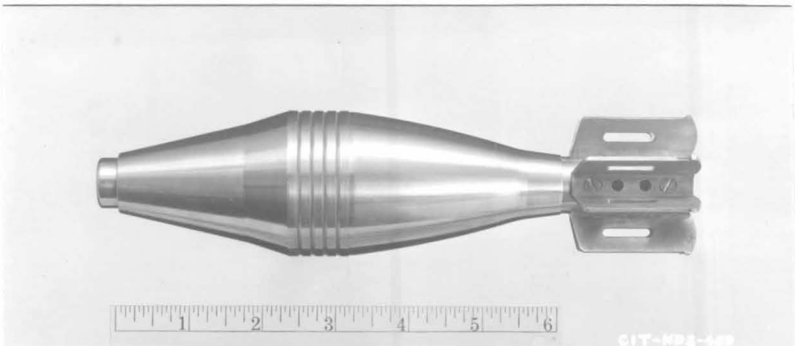

FIGURE 5
MODEL WITH
SMOOTH NOSE

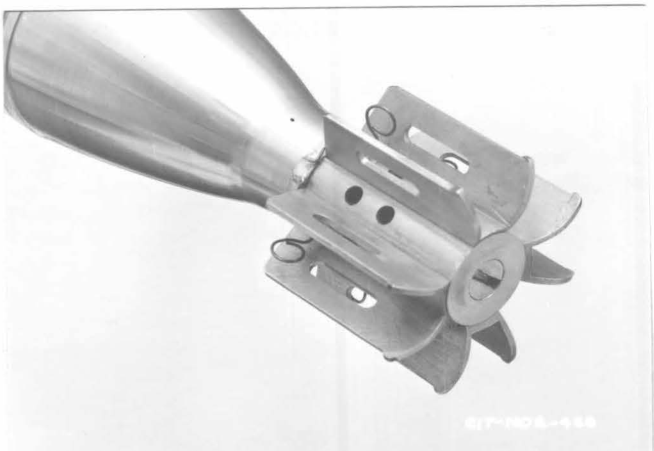

FIGURE 6
MODEL TAIL
WITH SPRING CLIPS

2" DIAMETER MODEL OF THE 60 MM. MORTAR PROJECTILE

[redacted]

[redacted]

[redacted] [redacted]

PROTOTYPE MODEL

(Runs 1-5, 18-21)

Most of the runs were made with a model having a smooth nose. A nose having the slider plug and safety pin was also tested to determine if these additions affected the performance. In two of these latter tests the safety pin was projecting at a radius of 1" (on the model as shown in Figure 4), but even with this condition the results were not appreciably different from those obtained with the smooth nose. Figures 4, 5, and 6 show the model as tested and the curve sheets give the results observed for Runs 1 to 5.

These tests show that the drag coefficient varies from 0.215 at zero yaw to 0.375 at 12° yaw. All but one of the tail alterations resulted in some increase in drag. The most serious defect in the prototype lies in the position of the center of pressure. This is but 0.015 of the length aft of the center of gravity at 2° yaw and increases to 0.045 L at 12° yaw. The changes in the tail design have been made with a view to increasing this center of pressure eccentricity, without too greatly adding to the drag.

The center of gravity is 0.488 L from the nose or nearly at the midpoint of the projectile. It has been suggested that the C.G. could be moved forward materially by making the nose of steel instead of plastic. This would no doubt increase stability very effectively, but the added weight of the projectile would have to be considered in its effect on the range.

The spring clips for holding the increment wafers were found to cause no appreciable difference in the test results.

[redacted]

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[redacted] [redacted]

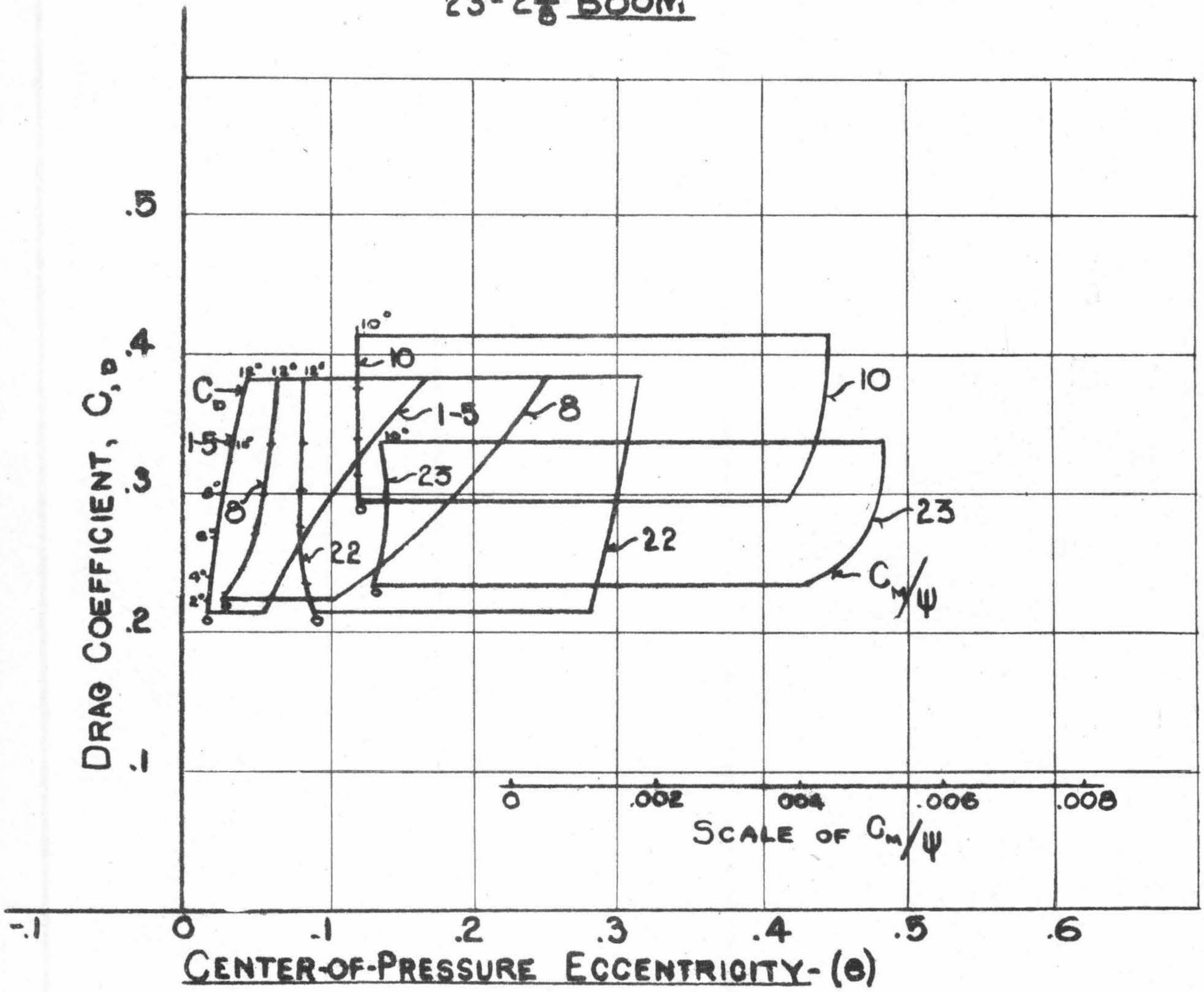
1-5 PROTOTYPE MODEL

8 - $\frac{3}{4}$" BOOM

10 - $1\frac{1}{8}$" BOOM & $\frac{5}{8}$" SHROUD

22 - $1\frac{1}{2}$" BOOM

23 - $2\frac{5}{8}$" BOOM



CHARACTERISTIC CHART - A
60MM MORTAR PROJECTILE

EFFECT OF LENGTH OF BOOM AND SHROUD

[redacted]

THE HIGH SPEED WATER TUNNEL AT CALIFORNIA INST. OF TECH

SHEET No. ND20-1271-L
PRINT NO.

RUNS-1-5, 8, 10, 22, 23
TESTS AUGUST, 1943

[redacted]

FIG. 7

[redacted]

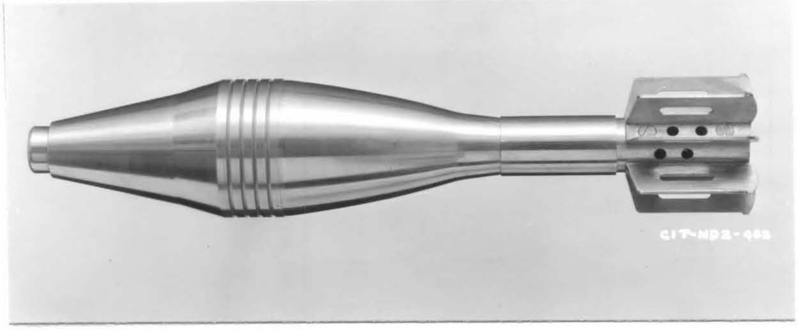


FIGURE 8

MODEL WITH 1-1/2" BOOM

TAIL WITH BOOM

(Runs 6-10, 22-25)

As both the center of gravity and center of pressure of the projectile are so near its midpoint, one of the obvious changes that could be made to better this condition would be to extend the tail assembly in order to increase the distance between the C.P. and C.G. Nine runs were made with tail booms of different lengths and with these tail booms in combination with modifications of the tail proper. Figure 8 shows the model with a 1-1/2" boom.

The lengths of booms tested were 3/8", 3/4", 1-1/8", 1-1/2", and 2-5/8". The Characteristic Chart, Figure 7, indicates clearly that the center of pressure eccentricity increases directly with an increase in boom length and with practically no increase in drag. The center of pressure eccentricity (e), is a measure of the stability as discussed in Appendix A. In calculating the center of gravity of the projectile with extended booms, it was assumed that the booms were tubular with a 1/8" thick wall.

In order to obtain a C.P. eccentricity of at least 0.08L, a boom length of 1-1/2" should be used. This would unquestionably add greatly to stability without materially increasing the drag. However, the added weight of the boom would have to be considered as affecting the range and the increased volume of the explosion chamber would, no doubt, reduce the effectiveness of the propellant charge. If the boom length could be increased to 2-1/2", the C.P. eccentricity would be approximately 0.12L and the moment would be over three times as great as that of the prototype model.

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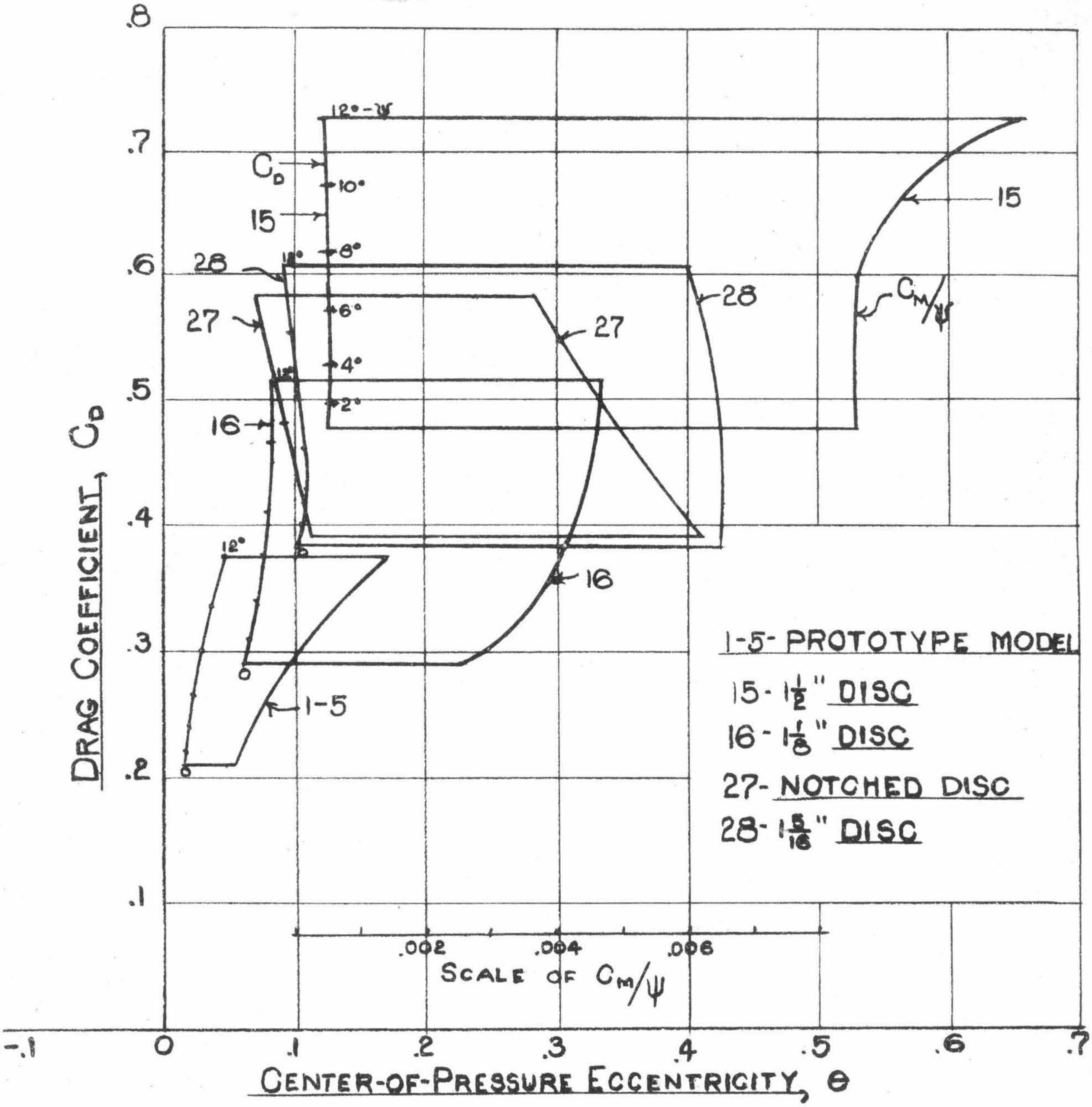

CHARACTERISTIC CHART-B
60MM MORTAR PROJECTILE

EFFECT OF VARIOUS TAIL DISCS

THE HIGH SPEED WATER TUNNEL AT CALIFORNIA INST. OF TECH.

SHEET NO. ND 20-1265L
PRINT NO.

RUNS 1-5, 15, 16, 27, 28
TESTS AUGUST, 1943

[redacted]

FIG. 9

[redacted]

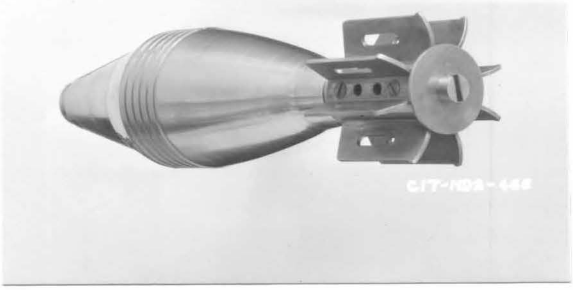

FIGURE 10

PLAIN DISC

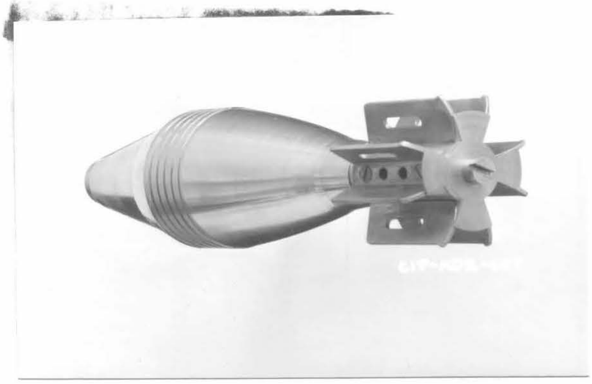

FIGURE 11

NOTCHED DISC

TAIL WITH DISC

(Runs 15-17, 24, 27, 28)

Several types and sizes of discs were tried on the rear of the tail assembly. Figure 10 shows a 1-1/8" diameter disc and Figure 11 a notched disc designed to give an equivalent resistance.

The Characteristic Chart (Figure 9), shows the effect on performance of these various discs. It is seen that the C.P. eccentricity is materially increased as are also the drag and the moment by the addition of a disc to the tail. It is apparent from the chart that a disc 1-5/16" in diameter would be required in order to increase the stability an appreciable amount. This diameter disc would give a C.P. eccentricity of a little over 0.10L and the drag would be increased from 0.215 to 0.38 at zero yaw. The moment, however, would be more than doubled. It must be remembered that increasing the drag, other factors remaining the same, decreases the range.

The notched disc (Run 27) was suggested as it was thought this could be made to give approximately the same characteristics as the plain disc and would have the advantage of simplicity of manufacture. It is believed this would cause less obstruction to the flow of the gases resulting from the explosion of the increment propellent wafers. The effect of the notched disc could be produced by a small projection on the fin punching which would be bent up and welded to the ends of the fins if necessary for stiffness. The Characteristic Chart, Figure 9, shows that the notched disc gives about the same results as the 1-5/16" diameter disc, although the increment of moment per degree of yaw decreases at a greater rate than with the plain disc.

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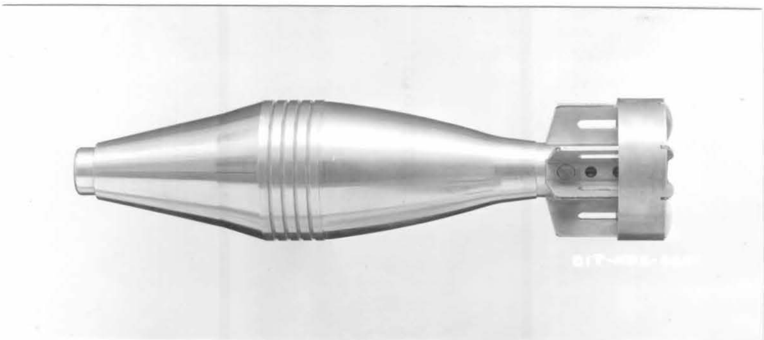

FIGURE 12

TAIL WITH 1-1/8" SHROUD

TAIL WITH SHROUD

(Runs 10, 11, 14, 17, 26)

Four runs were made with a shroud 5/8" wide and one with a 1-1/8" width. Some of these were in combination with booms and other tail modifications. The most promising of these runs was No. 10, being a combination of a 5/8" shroud and a 1-1/8" boom. On the Characteristic Chart, Figure 7, it is seen that this combination gave a C.P. eccentricity of 0.11L and a moment about as great as that of the 2-5/8" boom, although the drag was increased from 0.225 to 0.295 at zero yaw. One advantage of this arrangement over the longer boom would be that the shorter boom would have much less effect on the interior ballistics of the mortar. The 5/8" and 1-1/8" shrouds alone gave practically identical results and were not effective enough to justify their consideration.

[redacted]

[redacted]

[redacted]

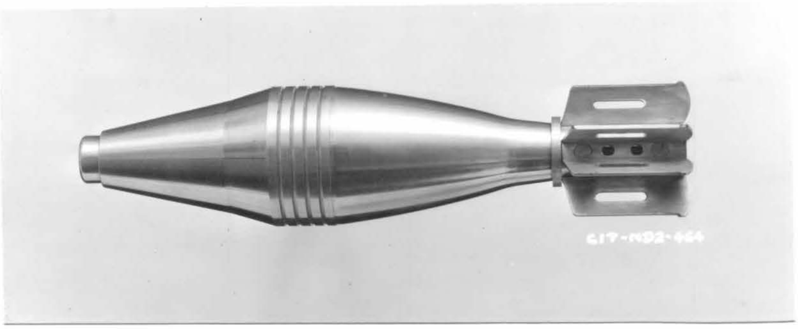

FIGURE 13

TAIL WITH 1" DIAMETER RING

TAIL WITH RING

(Runs 13 and 14)

One test was made with a 1" diameter ring placed forward of the tail as shown in Figure 13. This was the least effective of any of the changes that were tried. The moment and the C.P. eccentricity were both less than those of the prototype model. A ring 1-3/8" in diameter gave only a slight increase in the moment with a 65% increase in drag. These two runs indicate that practically no beneficial results can be obtained by a modification of this sort forward of the tail.

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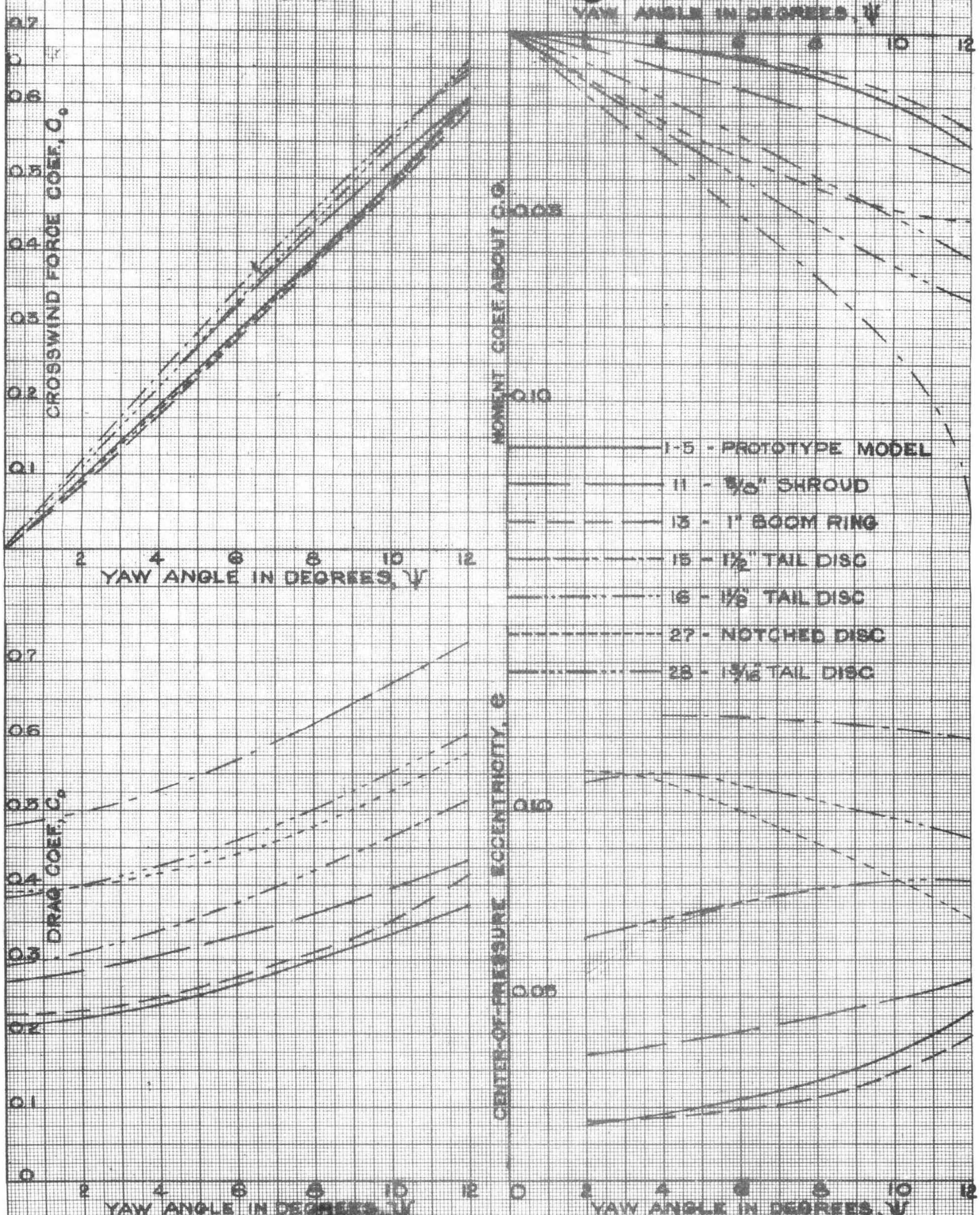
[redacted]



EFFECT OF TAIL DISC[redacted]GS, AND SHROUD

THE HIGH SPEED WATER TUNNEL AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY

SHEET NO. ND 20 - 1269 M

PRINT NO. ______

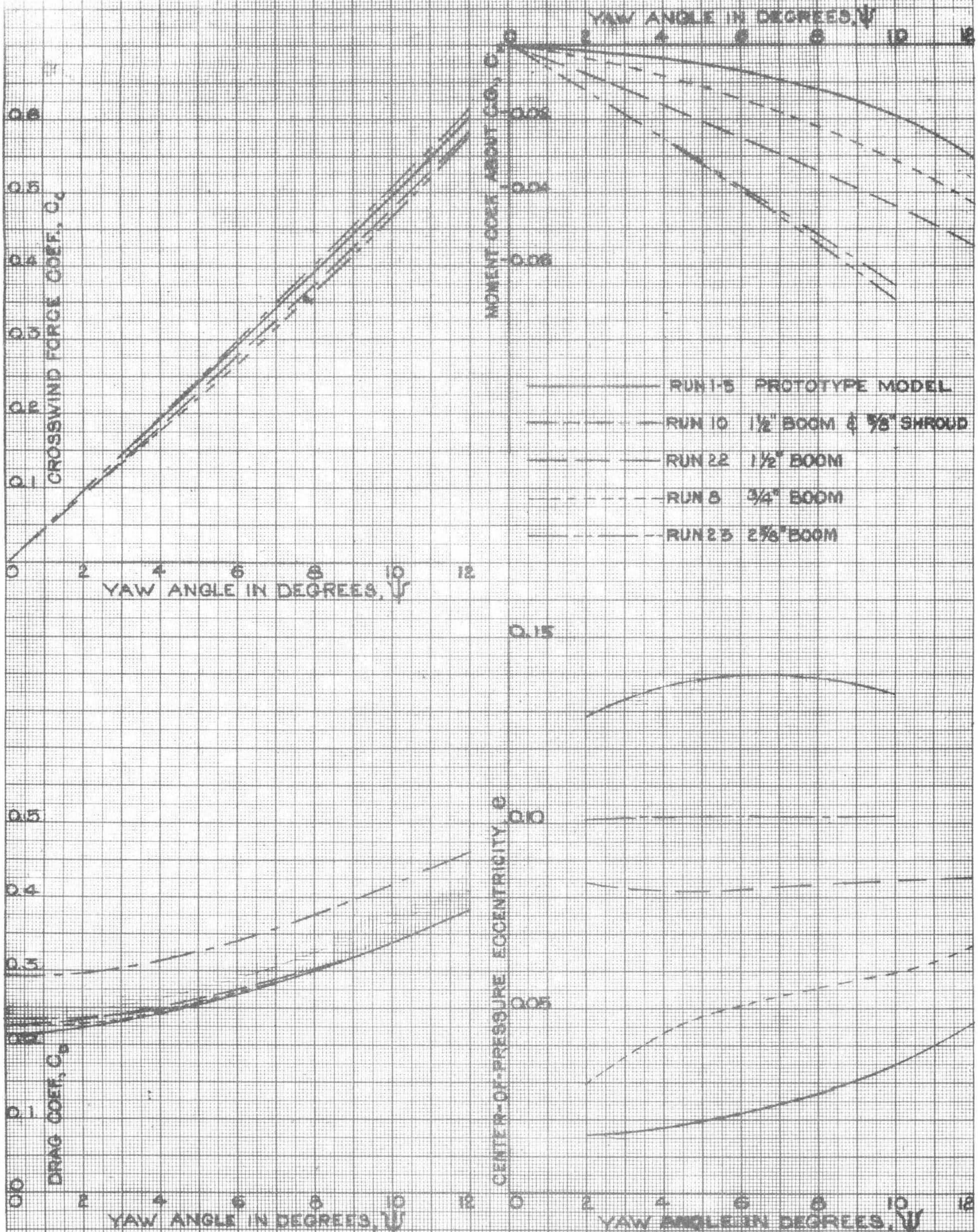
RUNS- 1-5, 13, 16, 27, 15, 11, 28

TEST- AUGUST, 1943

FIG. 14

[redacted]

[redacted]



EFFECT OF BOOM LENGTH

THE HIGH SPEED WATER TUNNEL AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY,
SHEET NO. ND 20 - 1270 M
PRINT NO.

RUNS 1-5, 8, 10, 22, 23
TESTS - AUG. 1945

FIG. 15

[redacted]

[redacted]

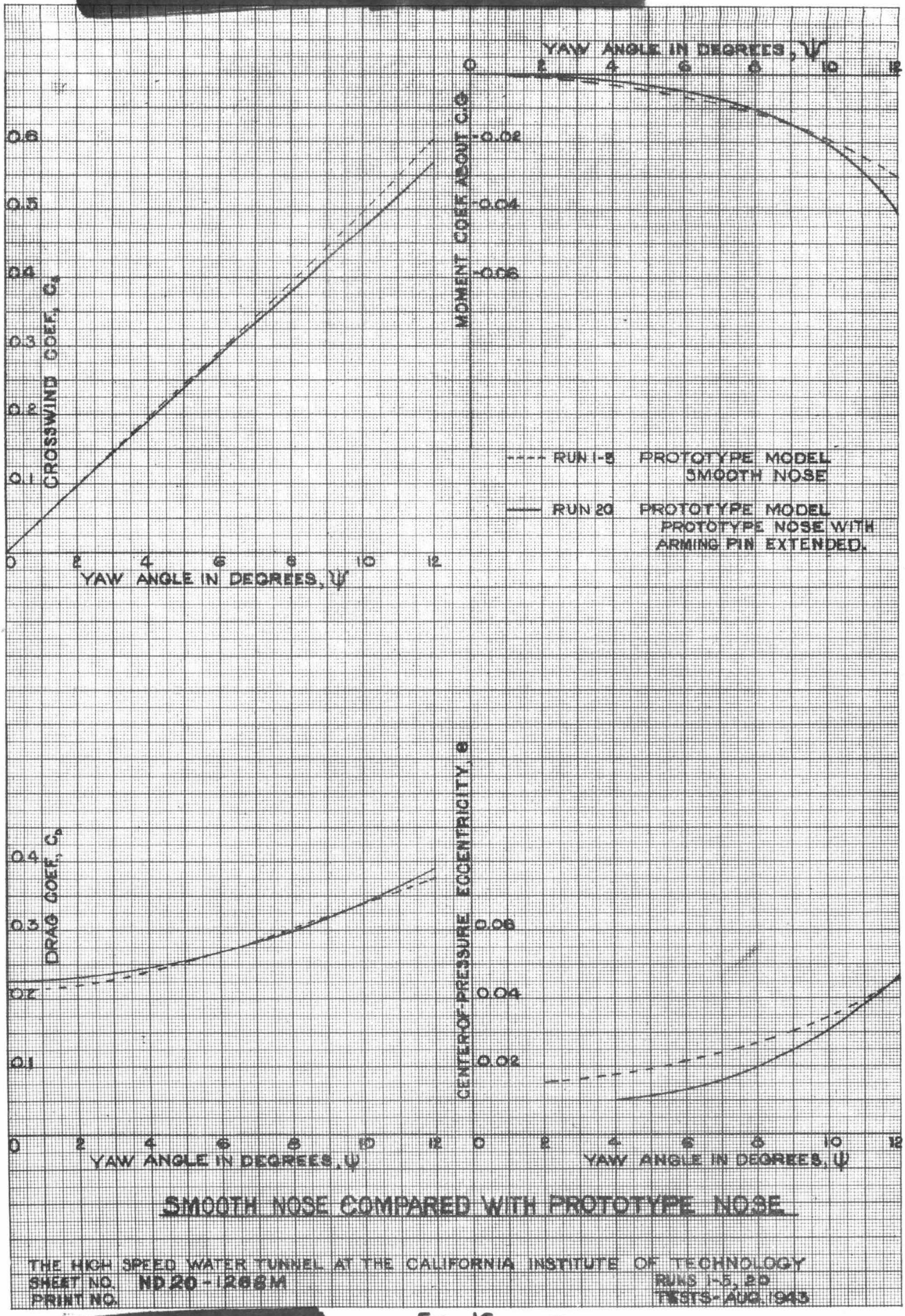


FIG. 16

[redacted]

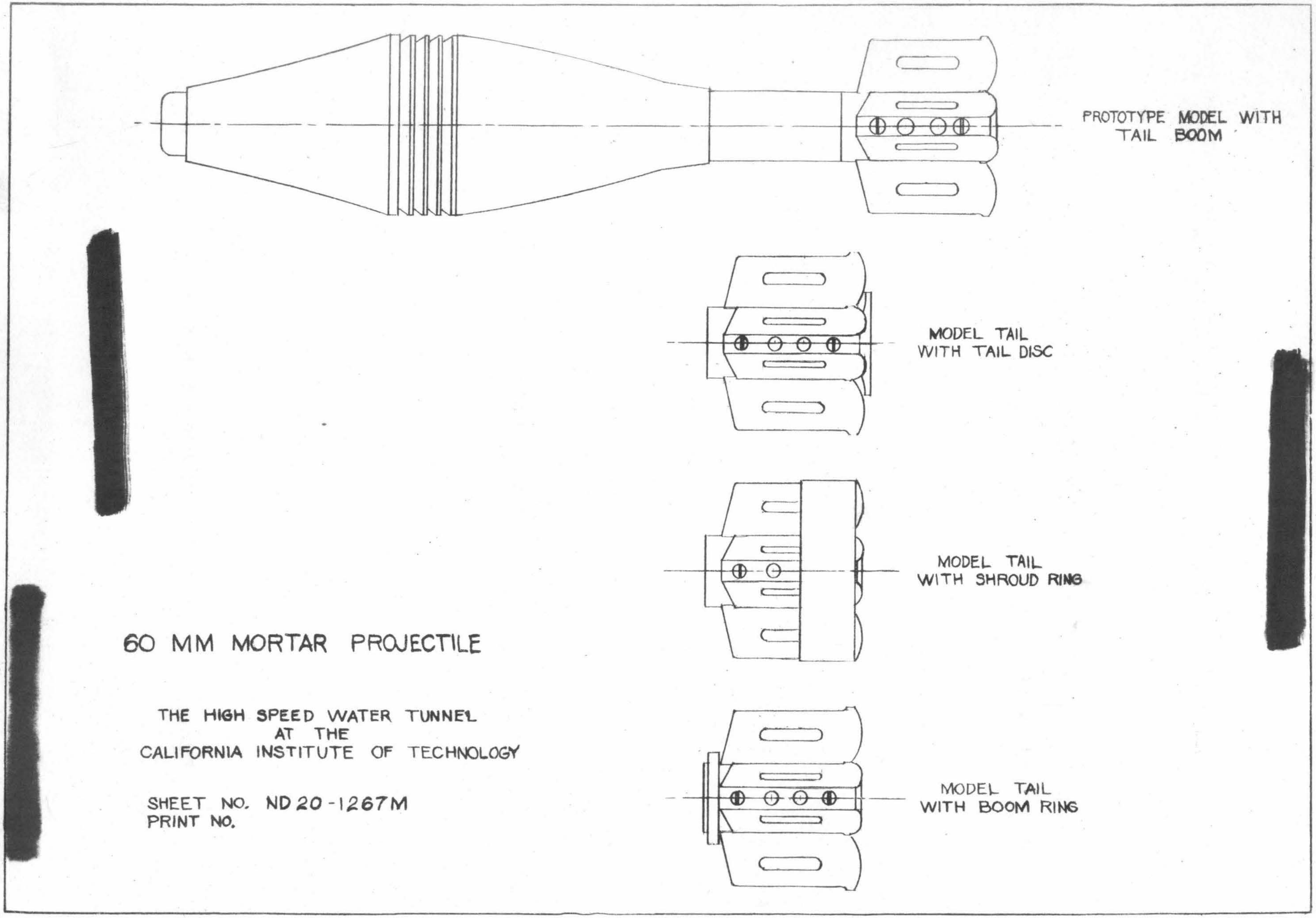

PROTOTYPE MODEL WITH TAIL BOOM
MODEL TAIL WITH TAIL DISC
MODEL TAIL WITH SHROUD RING
MODEL TAIL WITH BOOM RING
60 MM MORTAR PROJECTILE
THE HIGH SPEED WATER TUNNEL AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY
SHEET NO. ND 20-1267M
PRINT NO.

FIG. 17

[redacted]

FLOW LINE DRAWINGS
60 MM MORTAR PROJECTILE

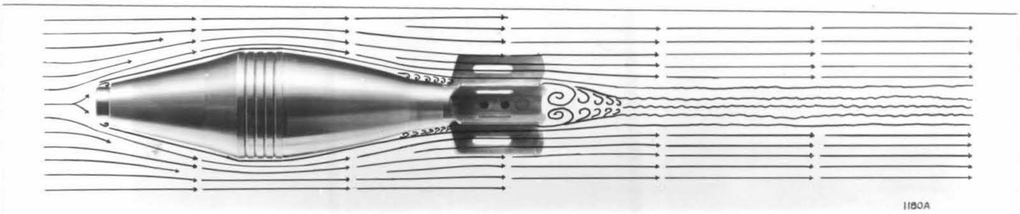


FIGURE 18

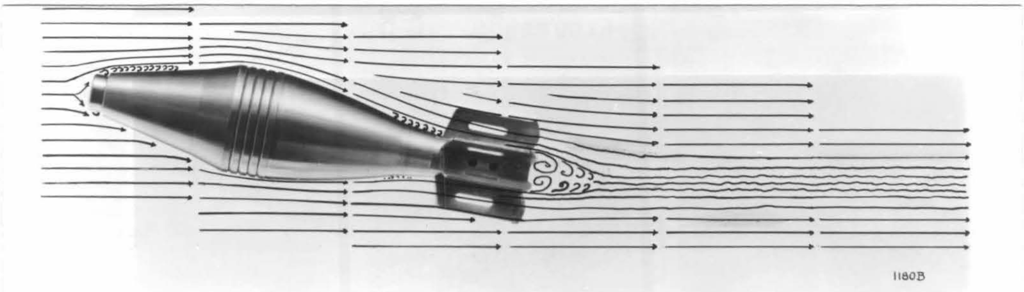


FIGURE 19
PROTOTYPE MODEL – 0° AND 10° YAW

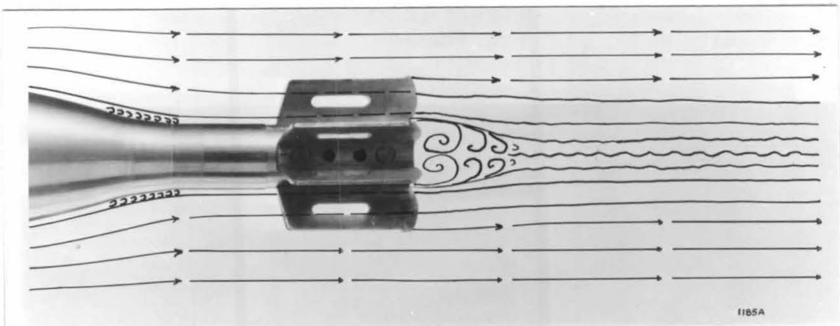


FIGURE 20

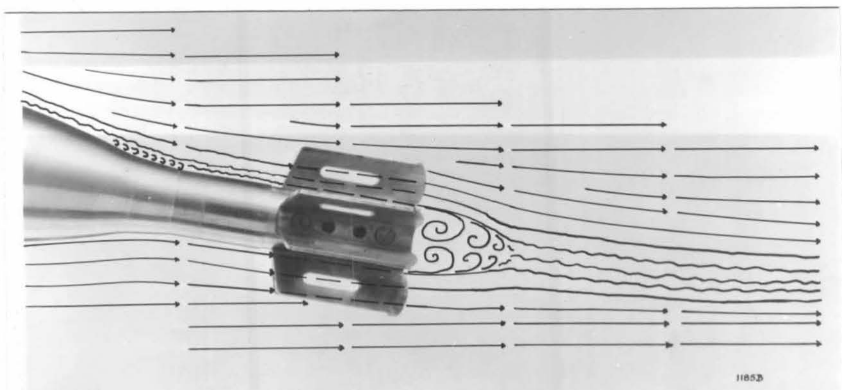


FIGURE 21
TAIL WITH 1-1/2" BOOM – 0° AND 10° YAW.

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[redacted]

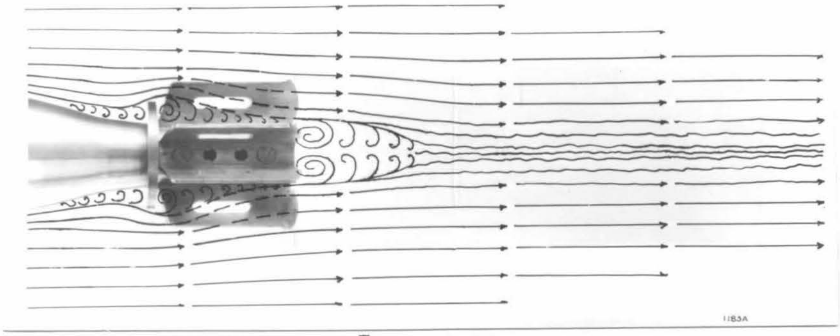


FIGURE 22

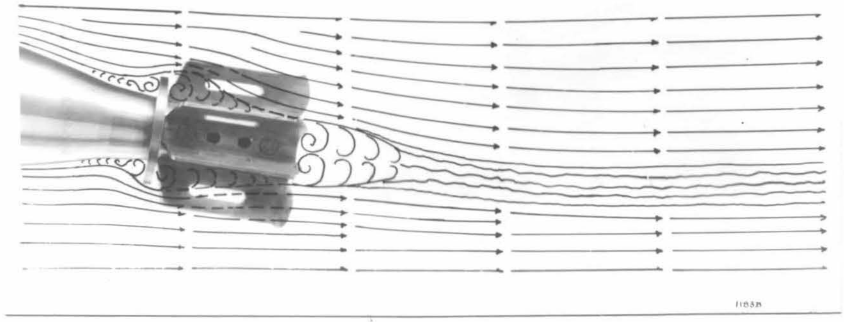


FIGURE 23
TAIL WITH 1" RING FORWARD — 0° AND 10° YAW

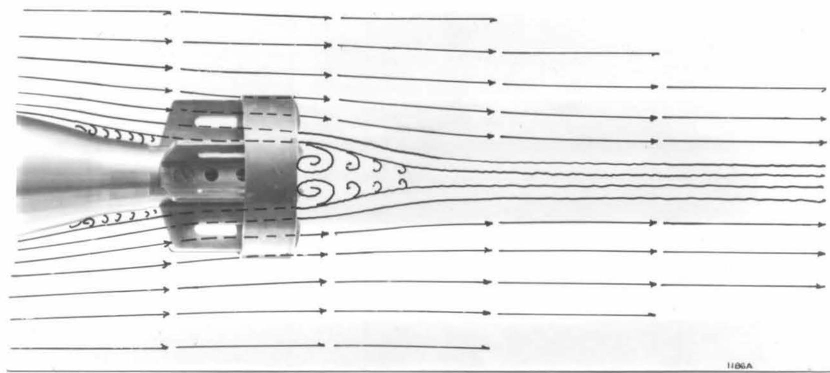


FIGURE 24

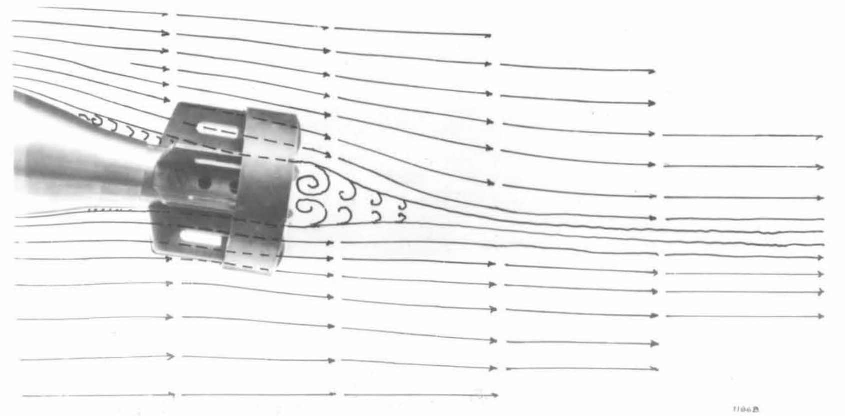


FIGURE 25
TAIL WITH SHROUD — 0° AND 10° YAW

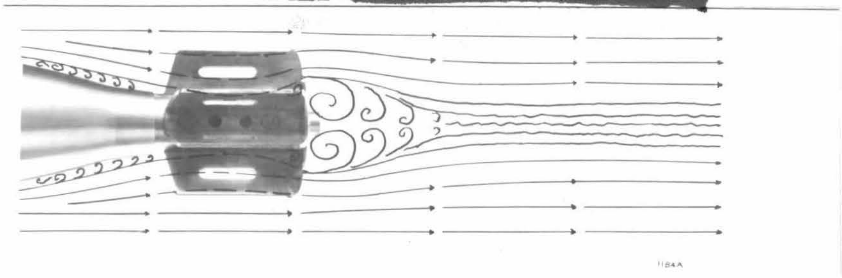


FIGURE 26

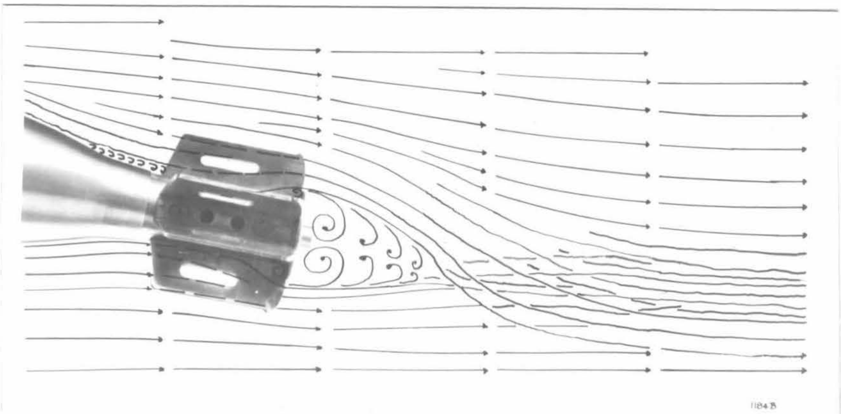


FIGURE 27
TAIL WITH 1-1/8" DISC – 0^{0} AND 10^{0} YAW

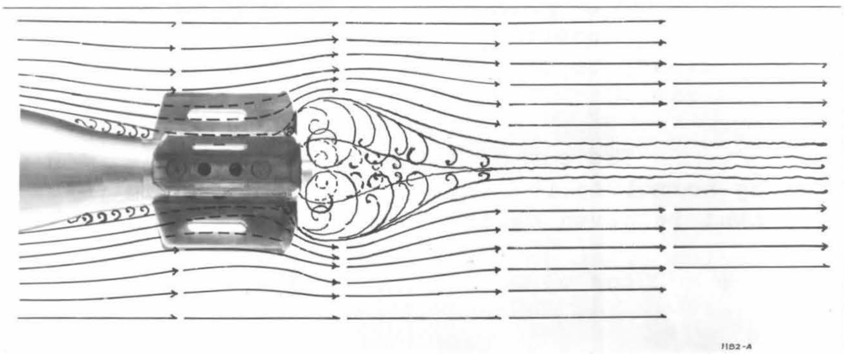


FIGURE 28

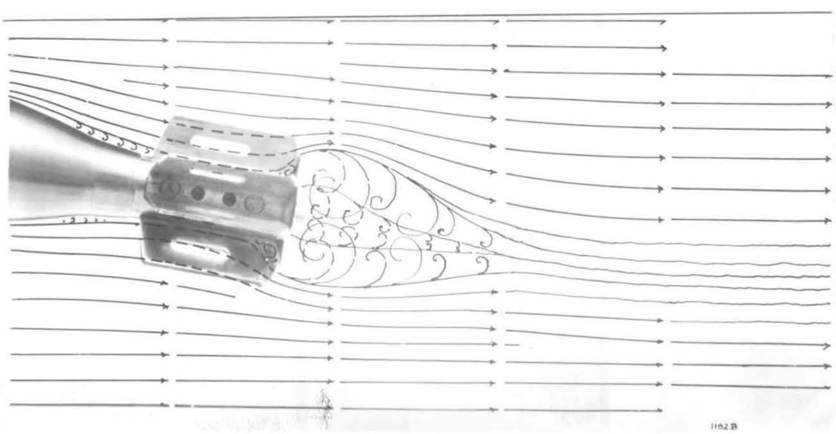


FIGURE 29
TAIL WITH NOTCHED DISC – 0^{0} AND 10^{0} YAW

[redacted]

APPENDIX A

DEFINITIONS

YAW ANGLE. The angle which the axis of the model makes with the direction of flow. Looking down on the model, yaw angles to the left are negative (-) and to the right, positive (+).

MOMENTS. Moments tending to rotate the model in a counter-clockwise direction (when looking down on the model) are negative (-), and those causing clockwise rotation, positive (+).

A moment has a destabilizing effect when it has the same sign as the yaw angle.

In all model tests the moment is measured about the point of support and is expressed in inch-pounds.

Moments about the center of gravity have the symbol, M_{cg}.

DRAG. The force, in pounds, exerted on the model parallel with the direction of flow.

CROSS FORCE. The force, in pounds, exerted on the model normal to the direction of flow. A positive cross force is defined as one acting in the same direction as the displacement of the projectile nose for a positive yaw.

NORMAL COMPONENT. The sum of the components of the drag and cross force acting normal to the axis of the model. The value of the normal component is given by the following:

$$N = (D \sin \psi + C \cos \psi)$$

in which

N = Normal component in lbs.

D = Drag in lbs.

C = Cross force in lbs.

ψ = Yaw angle in degrees.

CENTER OF PRESSURE. The point in the axis of the model at which the resultant of all forces acting on the model is applied. This is shown by the symbol (C. P.)

[redacted]

CENTER OF PRESSURE ECCENTRICITY. The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a fraction of the length (L) of the model. The center of pressure eccentricity (e) is derived as follows:

$$e = \frac{(L_{cg} - \bar{x})}{L} = \frac{1}{L} \frac{M_{cg}}{N}$$

in which

e = Center of pressure eccentricity

L = Length of model in inches

L_{cg} = Distance from the nose of projectile to CG-inches

$\bar{x}$ = Distance from the nose of projectile to CP-inches

COEFFICIENTS. The three force coefficients used are derived as follows:

Drag Coefficient, $C_D = \dfrac{D}{\rho \frac{V^2}{2} A_D}$

Cross Force Coefficient, $C_C = \dfrac{C}{\rho \frac{V^2}{2} A_D}$

Moment Coefficient, $C_M = \dfrac{M}{\rho \frac{V^2}{2} A_D L}$

in which

D = measured drag force in lbs.

C = measured cross wind force in lbs.

ρ = density of water in slugs/cu. ft.

A_D = area in sq. ft. of a cross section at the cylindrical portion of the projectile taken normal to the geometric axis of the projectile.

V = mean relative velocity between the water and the projectile in ft./sec.

[redacted]

[redacted]

M = moment in inch-lbs. measured about any particular point on the geometric axis of the projectile.

L = overall length of the projectile in inches.

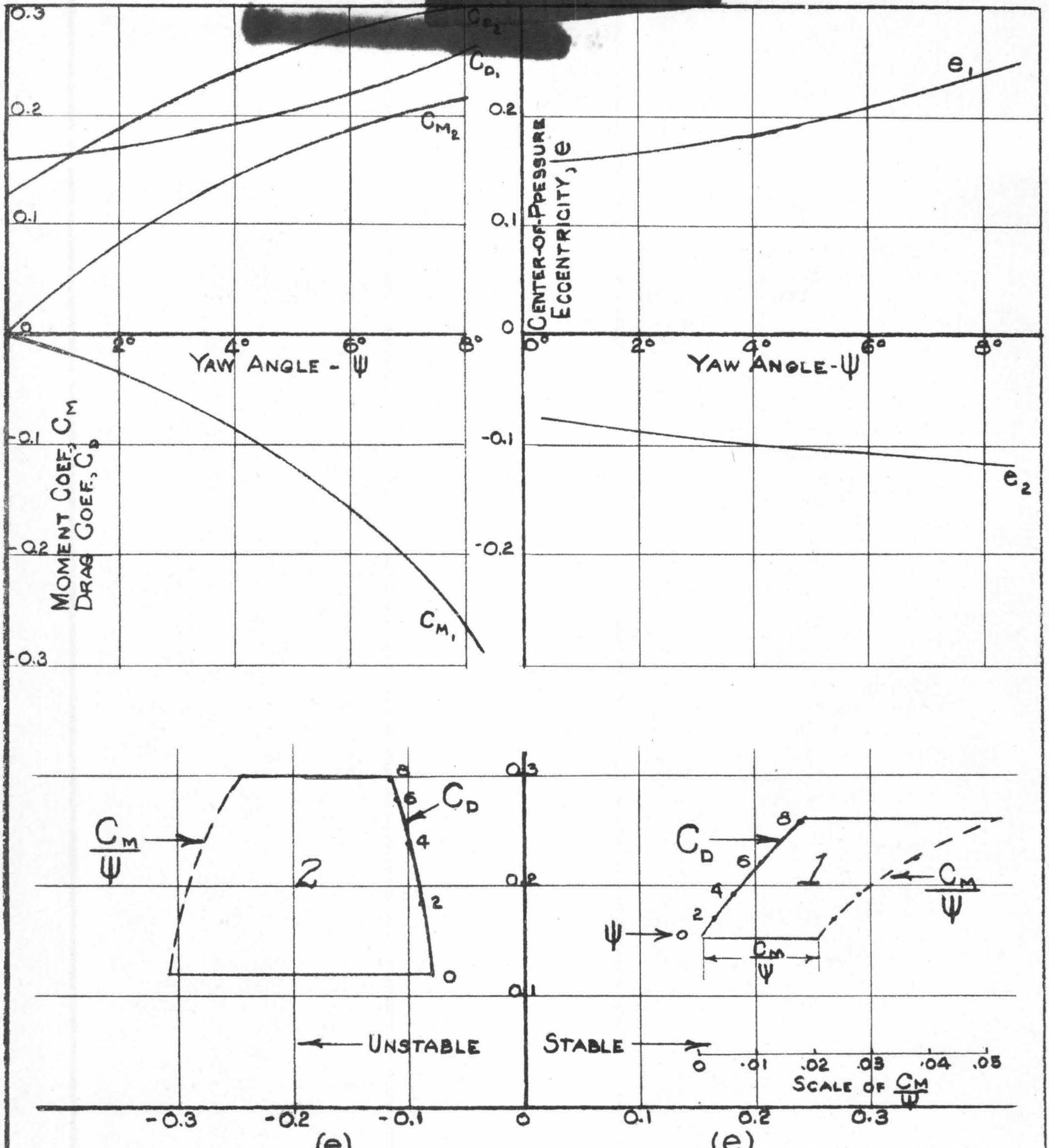
GENERAL DISCUSSION

The curves of force and moment coefficients and of center-of-pressure distance plotted as functions of the yaw angle are useful for a discussion of the stability of projectiles. Since these tunnel tests are made under steady flow conditions the results will only indicate the tendency of the projectile to return to or move away from the equilibrium position after a disturbance. Adopting aerodynamic usage, a projectile is said to be "statically" stable if it tends to return to equilibrium when disturbed. In the discussion of static stability the actual motion following the perturbation is not considered at all. In fact, a projectile may oscillate about the equilibrium position without ever remaining in it. In this case the projectile would be statically stable even though "dynamically" unstable. For a complete discussion of the mode of motion to be expected following a perturbation, the "dynamic" stability, additional information is necessary.

The condition for equilibrium is satisfied if C_M, calculated about the C.G. is equal to zero. In general, for projectiles with axial symmetry the moment is zero at $\psi = 0^{\circ}$, so that for equilibrium the projectile is oriented with its axis parallel to the direction of motion. If the projectile is rotated from the equilibrium position so as to give it a positive yaw angle, it is necessary that it have a negative moment coefficient, according to the sign convention adopted, in order that it be statically stable. Thus, a negative slope of the curve, C_M, vs. ψ corresponds to static stability, and a positive slope corresponds to instability. The degree of stability or instability is indicated by the magnitude of the slope. The same conclusions are obtained by interpreting the center-of-pressure curves. For symmetrical projectiles, if the center-of-pressure falls behind the center of gravity a negative, or restoring, moment exists and the projectile is statically stable. If the C.P. lies ahead of the C.G., the moment is non-restoring and the projectile is statically unstable. The degree of stability or instability is indicated by the distance between the center-of-gravity and center-of-pressure.

[redacted]

[redacted]



Description of Characteristic Chart

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THE HIGH SPEED WATER TUNNEL AT THE CALIF. INST. OF TECH.

SHEET NO. ND 20-1266L
PRINT NO.

[redacted]

APPENDIX B

DESCRIPTION OF CHARACTERISTIC CHART

The attached curve sheet shows typical curves for drag and moment coefficients and, also, center of pressure eccentricity, all varying with the yaw angle. Two cases have been assumed, indicated by the subscripts (1) and (2). Curves are selected merely to illustrate method of plotting chart and do not represent data on the projectile discussed in this report.

In order to obtain a better visualization of the performance indicated by the curves mentioned above, the "Characteristic Chart", shown at the bottom of the sheet, has been devised. In this chart the drag coefficient, C_D, is first plotted against the C.P. eccentricity, e. On this C_D curve are points opposite which are figures indicating the yaw angle, ψ. This C_D curve gives a clear indication of the variation in drag and C.P. eccentricity with yaw angle. Also, the position of the curve at the right or left of the vertical axis (+ e or - e) indicates whether or not the projectile is stable or unstable, in other words, whether the C.P. lies aft or forward of the center of gravity.

On this same chart is plotted the quantity C_M/ψ which gives an indication of the change in the moment coefficient, C_M, with varying yaw angle. This is done by dividing the C_M by the yaw in degrees and plotting these values, C_M/ψ, to a suitable scale, horizontally from the points representing the yaw angle. (In all cases the zero for the C_M/ψ scale is at the C_D curve).

The "Characteristic Chart" is useful as it gives a rather complete picture of the variation of three important characteristics of the projectile with changes in yaw angle. It is seen that Case 1 has much less increase in drag than Case 2. Also, that the C.P. eccentricity in Case 1 increases with the yaw and is positive, and therefore, tends to increase stability. In addition to this, the C_M is increasing at an INCREASING rate, indicating a proportional increasing resistance with increasing yaw angles. This is an additional stabilizing factor.

In Case 2 the opposite characteristics of Case 1 are indicated. Here, there is a greater increase in drag with increase in yaw, also, the C.P. eccentricity, which is negative, increases with the yaw, thus tending to increase instability. The change in moment coefficient occurs at a DECREASING rate, indicating a proportional decreasing resistance with increasing yaw. This is a destabilizing factor.

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[redacted]